THE STUDY OF AN AIR WASHER

BY

O. W. ARMSPACH

E. W. HAINES

ARMOUR INSTITUTE OF TECHNOLOGY

1917

THE STUDY OF AN AIR WASHER

A THESIS

PRESENTED BY

OTTO W. ARMSPACH AND E. WILFRED HAINES

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

MAY 31, 1917

APPROVED:

Professor of Mechanical Engineering

Dean of Engineering Studies

L. C. Monin

Dean of Cultural Studies

OBJECT

The object of this investigation is to find the efficiency of an air washer in removing various kinds of dust from the atmosphere.

THE STUDY OF AN AIR WASHER

CONTENTS

PART I

	Page
Foreword	2
Relation of dust to health	3
Methods of removing dust	5
Air washer efficiency	6
Cheese-cloth screen	6
Drexel Wash Bottles	7
Aitken Portable Dust Counter	8
Dr.Hill Apparatus	I9

PART 2

Apparatus used	26
Spray Nozzles	28
Test of Washer	35

THE STUDY OF AN AIR WASHER

LIST OF ILLUSTRATIONS

Fig.	Page
I-Aitken Dust Counter	I3
2-Aitken Dust Counter	I2
3-Microphotograph of Aitken sample	I5
4-Microphotograph of Dr.Hill sample	I5
5-Dr.Hill Apparatus bulb	I7
6-Diffractrascope	9
7-Drexel Wash Bottles	IO
8-Dr.Hill Apparatus	20
9-Dr.Hill Apparatus pump and bulb	I8
IO-Dr.Hill Apparatus connected to washer	36
II-Microphotograph of sample of rubber dust	38

THE STUDY OF AN AIR WASHER

FOREWORD

At the present time there are no standard methods of testing an air washer to determine their efficiency as a dust remover.

The subject will be presented in two parts:-

(I)-A general discussion of the principle,of air washers.

(2)-A method which was found to be the most suitable for determining the efficiency of a washer for removing dust from the air.

Indebtedness is expressed to Dr.E.V.Hill of the Bureau of Sanitation,who has made this investigation possible by rendering available the apparatus for air washer testing located in the City Hall,Chicago;and also to Professor A.H.Anderson for the suggestions offered by him.

THE STUDY OF AN AIR WASHER

RELATION OF DUST TO HEALTH

One of the essential requirements in ventilation work,and one which in the past has not been given the attention it deserves, is the purity of the air supply.When we speak of air purity the usual inference is that the air is free from contamination. Impurities from this source are probably less injurious than the dust in the air supply.It is commonly thought that all outdoor air is fresh and pure.This is far from true in cities where air laden with dust,dirt and soot is drawn into the buildings by systems of artificial ventilation.The fact that dust is more than a mere inconvenience,and that it may give rise to objectionable odors when it enters the rooms,makes it plain that systems of air washing must come into general use where mechanical ventilation is required.It is also

usual to re-circulate air in mills for economy of heat in cold weather,and the dust which has been taken up must be removed before the air can be used again.

THE STUDY OF AN AIR WASHER

METHODS OF REMOVING DUST

The methods employed to remove dust from the air are:-

(I)Cheese-cloth screens.This method however is very inefficient.

(2)A room filled with coke,over which water runs continuously.The air comes in contact with the coke,and a part of the dust is washed out.This method is very unsanitary and is very little used.

(3)Water is passed over a series of plates arranged to provide a curtain of water through which the air is forced.

(4)Passing the air through a mist of water formed by spray nozzles.The air must also pass through a system of scrubbing surfaces which remove any soot,cinders or grease-covered particles that may be carried through the water.

THE STUDY OF AN AIR WASHER

AIR WASHER EFFICIENCY

What is the efficiency of an air washer? It is the ratio of the dust removed by the washer to that of the dust entering.This involves the task of determining the amount of dust,either by weight or number of particles, contained in a cubic foot of air.The methods heretofore employed have been crude,and aroused doubt as to their value.

DUST DETERMINATION

Dust in the air consists of particles varying from sizes visible to the naked eye to those invisible even under the microscope.They are continually in motion,and it is this fact that accounts for the difference in the dust count in different parts of the same room.

Cheese-cloth Screen

One of the first attempts was the use of a cheese-cloth screen placed before the washer, and another after the eliminator plates.These

THE STUDY OF AN AIR WASHER

These were left in place for several hours, and the air was forced through them. Some idea of the efficiency could be obtained by comparing the dirt and dust on the screens. The objection to this method is that the screens must be left in position for many hours, and a quick determination is impossible.

DREXEL WASH BOTTLE METHOD

This method is more accurate than the preceding but it also has its objections. In this case the dust is weighed, but the fineness of the dust is not considered. The apparatus consists of a bottle containing distilled water, through which a sample of the air is passes. By evaporating the water, the weight of dust given up by the air may be obtained. In order to determine the amount of air, that has passed through these bottles an air meter is used. From the weight of dust obtained and the volume of air going through

the meter,the weight of dust per cubic foot of air is found.This method requires many hours, which is the chief objection to its use.It has been claimed that air after bubbling through a body of water must be free from dust.Dr.Hill has taken a sample of air,after it had been passed through a bottle of distilled water, and placed it in a diffractrascope through which a beam of light was passed.The beam of light could be seen.A beam of light is only visible,when air contains dust particles. From these results it seems that the air after bubbling through the wash bottle is not necessarily dust free.If these facts are true there is an error in the wash bottle method for determining the dust in air.

AITKEN PORTABLE DUST COUNTER

This form of machine gives fairly consistent results.(See figures I & 2) It consists of a precipitation chamber with a

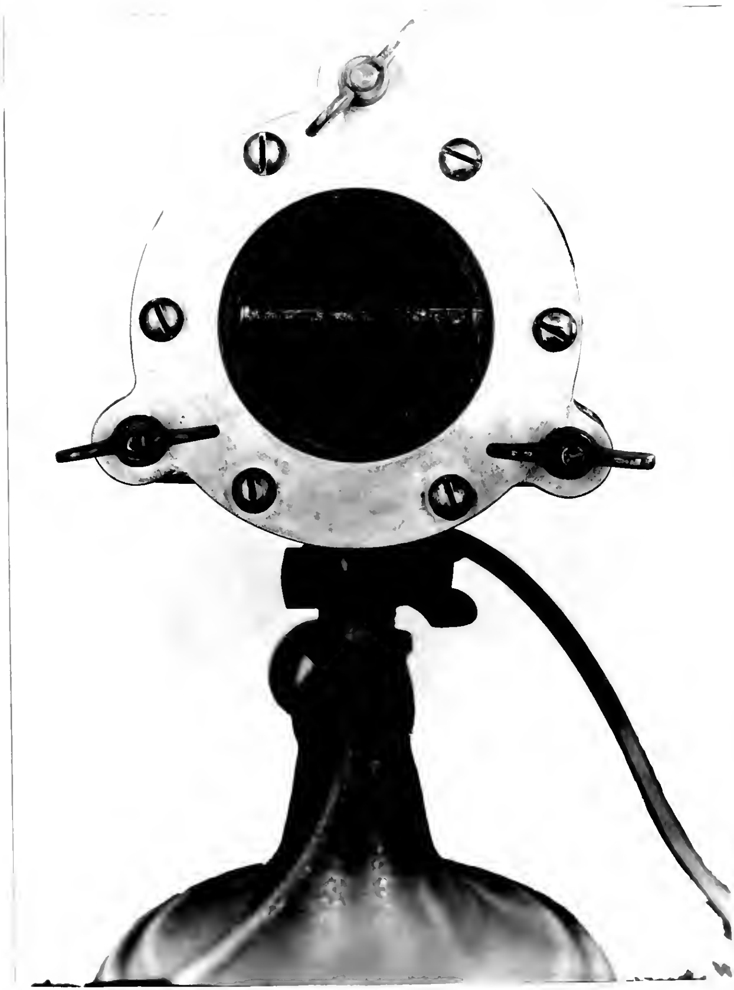


Fig.6- Diffractrascope showing beam of light reflected by dust particles

Fig.7-Drexel Wash Bottles in position on washer and spray nozzles.

THE STUDY OF AN AIR WASHER

pump,filter,eyepiece,and air measuring devices mounted on a tripod in a very convenient manner. The precipitation chamber (a) holds exactly 50 cubic centimetres.The stop socks (b and c) are bored and calibrated to hold one quarter and one twentieth of a cubic centimetre respectively.The chambers of these cocks are bored horizontally as well as vertically,so that air may be passed through from the folter,or a measured quantity introduced from the outside.These are situated between the filter (d) and the precipitation chamber.If these cocks are set longitudinally,and the pump (e) is operated,the air is drawn into the opening (o) through the filter and into the precipitation chamber.The pump piston is depressed ten or twelve times in this manner removing all residual air and dust in the apparatus.The three-way cock (b) is now turned horizontally and the bore is filled with the air to be sampled by means of the rubber tube (n).

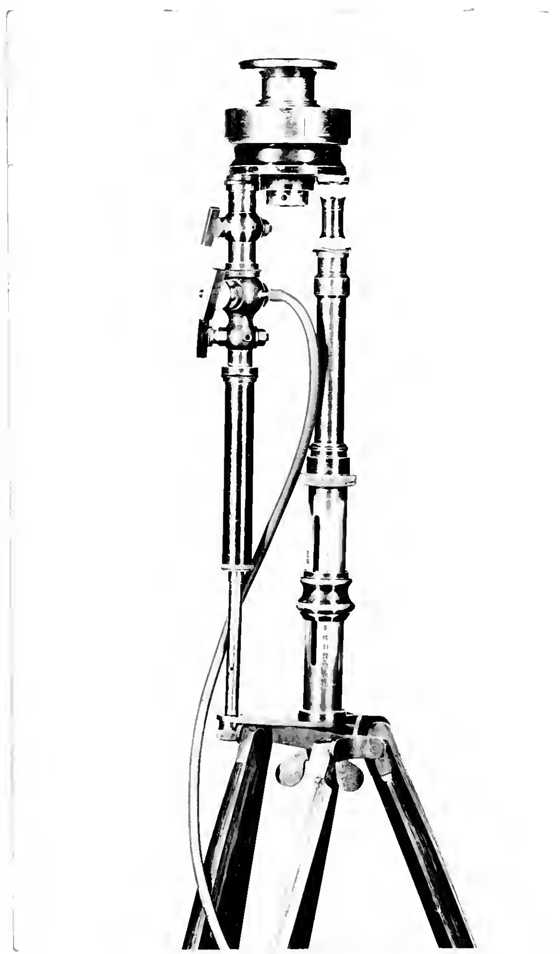


Fig.2-Aitken Portable Dust Counter

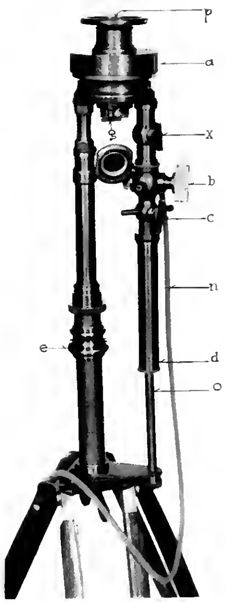


Fig.I-Aitken Dust Counter

THE STUDY OF AN AIR WASHER

This is done by merely drawing air in with the mouth and turning the oock at the same time. Now close cock (x) and take a stroke with the pump returning it to the top position.This lowers the pressure in the chamber,which is lined with a hygroscopic material that is kept moist with water.Now open the cock (x) Since the pressure in the chamber is less than atmospheric pressure the air that is trapped in the cock (b) rushes into the chamber.By means of thé stirrer (q),the mixture of filtered and atmospheric air is thoroughly agitated with about 75 turns.The next step is to lower the pressure in the chamber by taking about four strokes with the pump.This causes the air to expand adiabatically below the dew point,and condensation occurs.Each part-icle of dust present forms a nucleus for this condensation which drops to the bottom of the chamber upon the ruled glass.The drops may

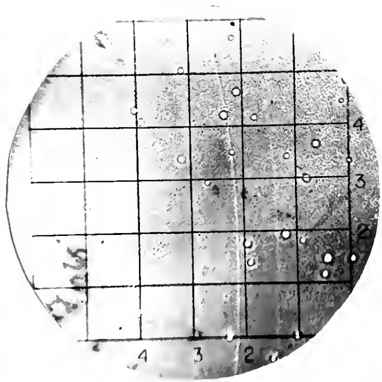


Fig.3-Microphotograph of sample taken with

Aitken Dust Counter.

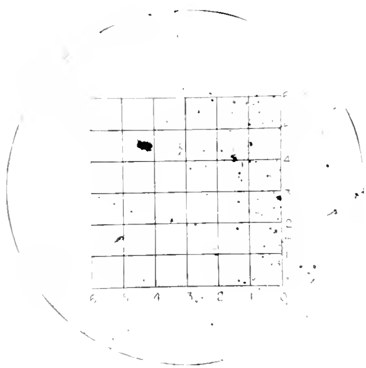


Fig.4-Microphotograph of sample taken with

Hill Dust Counter.

now be counted through the eyepiece at the top of the instrument.

By noting the dilution of the sample and counting the number of dust paricles in a given portion,the total number of particles per cubic centimetre can be calculated.

A modification of this method,suggested by Mr.Hoskins is to use a small smoked disc of glass in place of the ruled glass.The plate can now be used as a permanent record, and counted at any time.

This form of dust counter,although giving usfairly consistent results,we found was not suitable for our work on air washer testing. With this instrument it is impossible to take two samples,one before the spray and one after the spray,at the same time.The instrument also requires an exceptional amount of care in handling.Figure (3) shows a microphotograph of a dust sample from the Aitken Dust Counter.

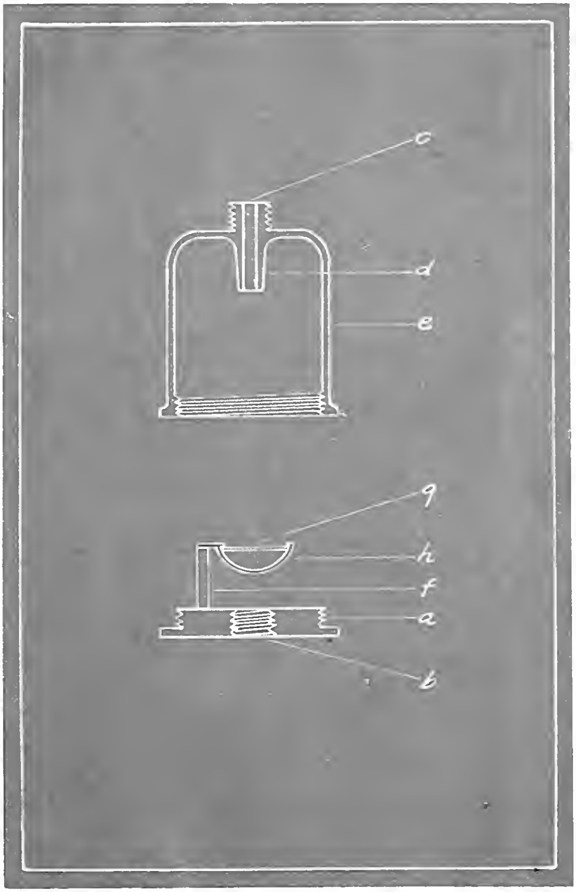


Fig.5-Hill bulb

Fig.9-Pump and bulb of Dr.Hill Apparatus

THE STUDY OF AN AIR WASHER

THE DR.HILL APPARATUS

This is probably the form of machine best adapted to air washer testing at the present time.(See fig.5).It consists of a pump having a capacity of four cubic centimetres,and six bulbs,each containing a coverslip to catch the dust.The bulb is made of a base (a) and a top (e).The base holds a post (f) which contains three fingers (h).The purpose of these fingers is to hold a five-eighth inch cover slip (q). In the center of the base is a one-eighth inch hole (b) through which air passes to the pump. The top which is threaded to receive the base contains a one-eighth inch inlet (e).When the bulb is in place the inlet (d) extends to within one thirtysecond of an inch from the cover-slip.

The entire apparatus consists of a pump and six bulbs.These are all connected in series to the pump.Now if a stroke is taken,air enters

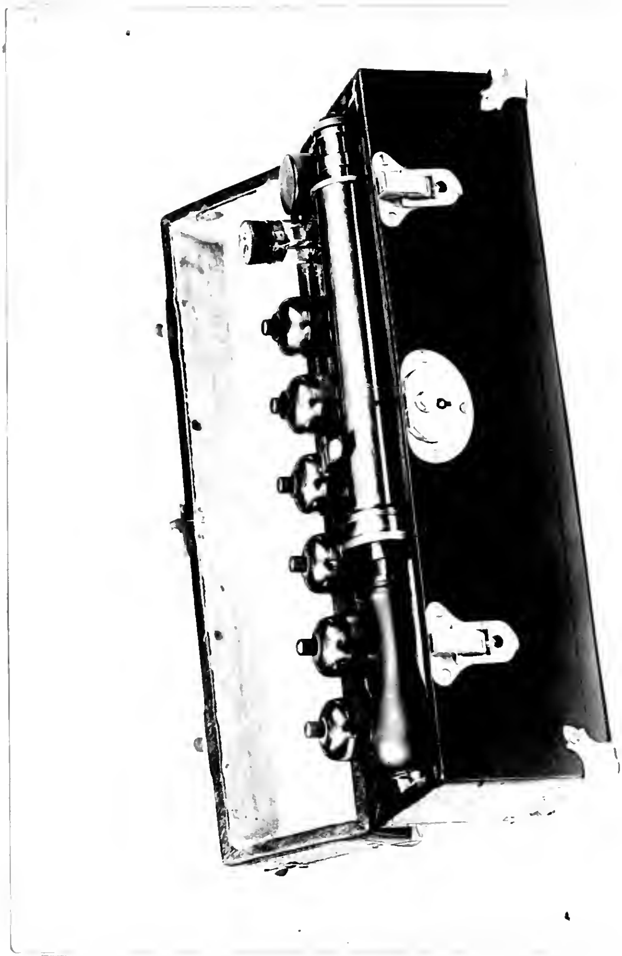


Fig.8 -Dr.Hill Apparatus forcounting dust particles

THE STUDY OF AN AIR WASHER

the top bulb,passes through the remaining five and then into the pump;but as the air enters it impinges against the cover slips in each bulb. On these cover slips is placed a mixture of varnish,glycerine,and linseed oil.Each of these three ingredients has its purpose.The varnish has the necessary sticky quality required to hold the particles of dust as they impinge against the plate.The linseed oil is used to to dilute to the required consistency.As some time is required to take a sample,there must be a substance present which will not readily thicken.If this should occur the particles would merely stick to the plate and again leave it,thereby giving us erroneous results.To overcome this,glycerine is added to the varnish. This mixture forms a substance that will not thicken within twenty four hours.

After having placed the six bulbs in series with the pump,and placed a cover slip containing

a coating of the mixture in each bulb the instrument is now ready for a sample to be taken. Hold the apparatus in a vertical position and take a number of strokes with the pump.The number of strokes,that are to be taken depends on the quantity of dust in the air,For ordinary room conditions the number of strokes is between twenty and forty.The six cover slips are now removed and each one is inverted on a small glass plate measuring one inch by three inches.The varnish causes the slip to adhere to the glass.Thus a permanent record of the sample is formed.This is placed under a microscope and with the aid of the ruled objective the dust particles on the plate may be counted. Knowing the amount of air that was used to c cause this dust deposit,the dust count may be readily computed for one cubic foot of air.

After many experiments with this instrument Dr.Hill has been able to calibrate it in such

a way as to avoid the use of all six bulbs.It was found that six bulbs were required to prevent any particles from entering the pump,but a definite per centage was caught by the first bulb.This was found by numerous experiments to be sixty two per cent.

The number of particles per cubic foot are directly proportional to the count on the cover slip and inversely proportional to the number of strokes.The equation may therefor be written that:-

D= Kd divided by n

where:-

D equals the number of particles per cubic foot

K equals a constant depending upon the calibration of the instrument and the ruled glass in the objective of the microscope

d equals the particles counted on the first bulb that are covered by the squared glass.

n equals the number of strokes made with the pump

THE STUDY OF AN AIR WASHER

The ruled glass used, covered 72.5 per cent of the dust on the cover slip. From this data an equation giving the count per cubic foot may be written.

D equals I728d divided by .62x72.5x4xn

Therefor D equals 960d divided by n.

This is the form of instrument that was found best suited for air washer testing. It gives a means of obtaining comparatively quick counts. Later in this report is explained a method of taking two samples simultaneously, a feature which is necessary in dust testing for determining the efficiencies of air washers. Another advantage of this counter is that a permanent record of the count is established, which may be referred to at any future time. It also affords a means of investigating the nature of the dust and the comparative size of the dust particles.

PART TWO

A method which was found to be the most suitable for determining the efficiency of a washer for removing dust from the air.

THE STUDY OF AN AIR WASHER

APPARATUS USED

The apparatus used in this investigation consisted of a specially designed washer connected to a 55 inch multi-vane blower.The air is drawn through the washer and discharged through a I9 inch galvanized iron duct ten feet long.The blower is driven by a belt from a three horse-power direct current motor,The motor is of the constant speed type,operating on a 220 volt line and running at I650 r.p.m.

The nozzles are supplied with water from a centrifugal pump directly connected to a constant speed motor.A gauge is located on the discharge line to the nozzles and indicated throughout the entire test a pressure of I7 pounds per square inch.

The washer inlet measures two feet six inches wide by three feet nine inches high.Between the inlet and the eliminator plates are two banks of spray nozzles,the first having 28,and

THE STUDY OF AN AIR WASHER

the second 22.The distance between the two banks is two feet five inches.The eliminator plates are four feet nine inches from the first bank of nozzles,and are washed by six nozzles placed at the top of the washer.

Anemometer readings taken at the I9 inch outlet show a velocity of 3000 feet per minute through the duct.

The area of the duct is equal to 3.I4I6x I9xI9 divided by 4xI44 which equals I.97 square feet.

Q equals FV

" I.97x3000

" 5900 cubic feet per minute.

The area traversed by the air in passing through the washer is equal to 45x30 divided by I44 which equals 9.37 square feet.

The velocity of air through the washer is 5900 divided by 9.37 which equals 630 feet per minute.From this the number of cubic feet of

air washed per nozzle may be calculated and which equals 5900 divided by 28 plus 22 plus 6, equals I05.2 cubic feet of air washed by each nozzle.

SPRAY NOZZLES

An air washer requires that the nozzles should producea finely atomized spray,so that the entire spraying chamber is filled with a mist.This allows the particles of dust to remin in contact with the water for a comparatively long time.In order to break the water into fine particles requires a nozzle having a low coefficient of discharge.This was shown by tests made on two different nozzles,one producing a fine mist and the other a course spray.The discharge and coefficient was determined by weighing the actual water passing through the outlet by means of a platform scales.The theoretical discharge was obtained by connecting a mercury column ten inches from the tip of the nozzle.Data from the tests may be found on the

V

THE STUDY OF AN AIR WASHER

two following pages.

THE STUDY OF AN AIR WASHER

NOZZLE NO.I

Run	Head in Ft. of water	Theor.Disch. C.F.M.	Act.Disch. C.F.M.	COeff.of Disch.
I	3.4I	.I7I9	.04I0	.237
2	5.66	.2220	.0569	.256
3	7.95	.2640	.0697	.264
4	I0.20	.2990	.080I	.268
5	I2.48	.3290	.0897	.272
6	I4.76	.3580	.0962	.269
7	I9.30	.4II0	.II20	.272
8	24.98	.4660	.I250	.268
9	30.60	.5I60	.I378	.267
I0	36.30	.5630	.I540	.273
II	42.00	.6050	.I668	.275
I2	47.60	.6440	.6440	.274

This nozzle produced a very fine spray at an angle of 45 degrees from the vertical.The actual discharge as measured at I7 pounds pressure was .I607 c.f.m. or I.2 gallons.

Diameter of nozzle equals three sixteenths inches

THE STUDY OF AN AIR WASHER

SAMPLE CALCULATIONS

Diameter of outlet .I875 inches

$$A = \frac{3.1416 \times .1875 \times .1875}{4 \times 144}$$

$$= .000192 \text{ square feet}$$

$$V = \sqrt{2gh}$$

$$= \sqrt{64.4 \times 2.26}$$

$$= 12.04 \text{ feet per second}$$

$$= 722.4 \text{ feet per minute}$$

$$Q = FV$$

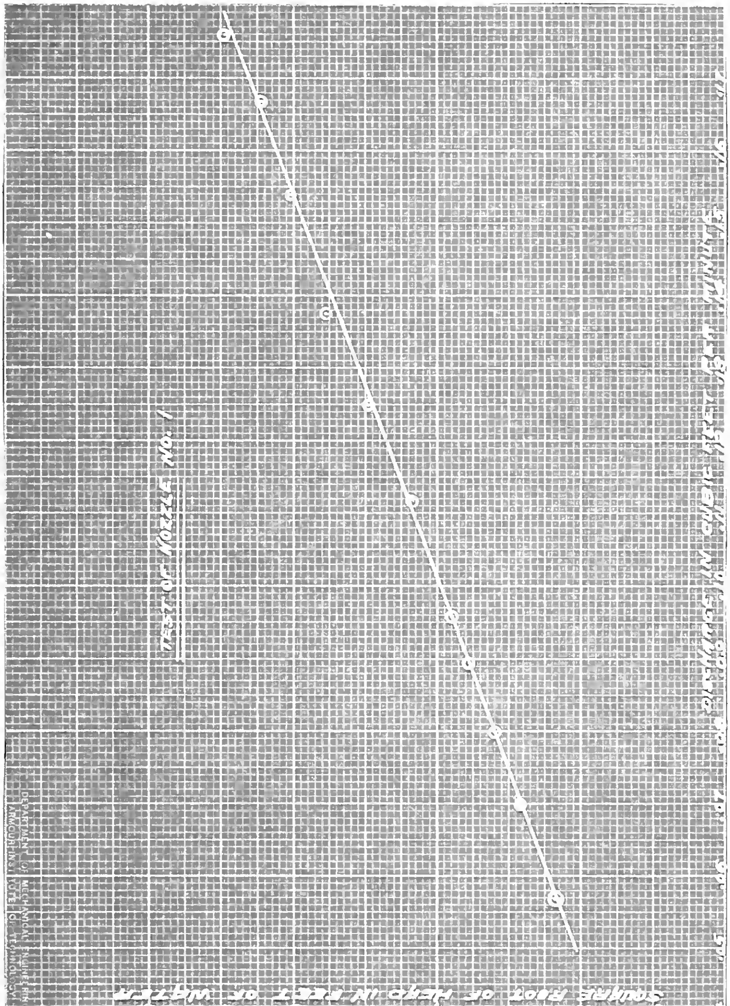
$$= .000192 \times 722.4$$

$$= .139 \text{ cubic feet per minute}$$

The actual discharge as measured was 6.5 pounds per minute or .I04I cubic feet per minute. Therefor the coefficient of discharge is:-

$$C = \frac{.1041}{.139}$$

$$= .75$$


TEST OF NOZZLE No. 1
DISCHARGE IN CUBIC FEET PER MINUTE
SQUARE ROOT OF HEAD IN FEET OF WATER
DEPARTMENT OF MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY

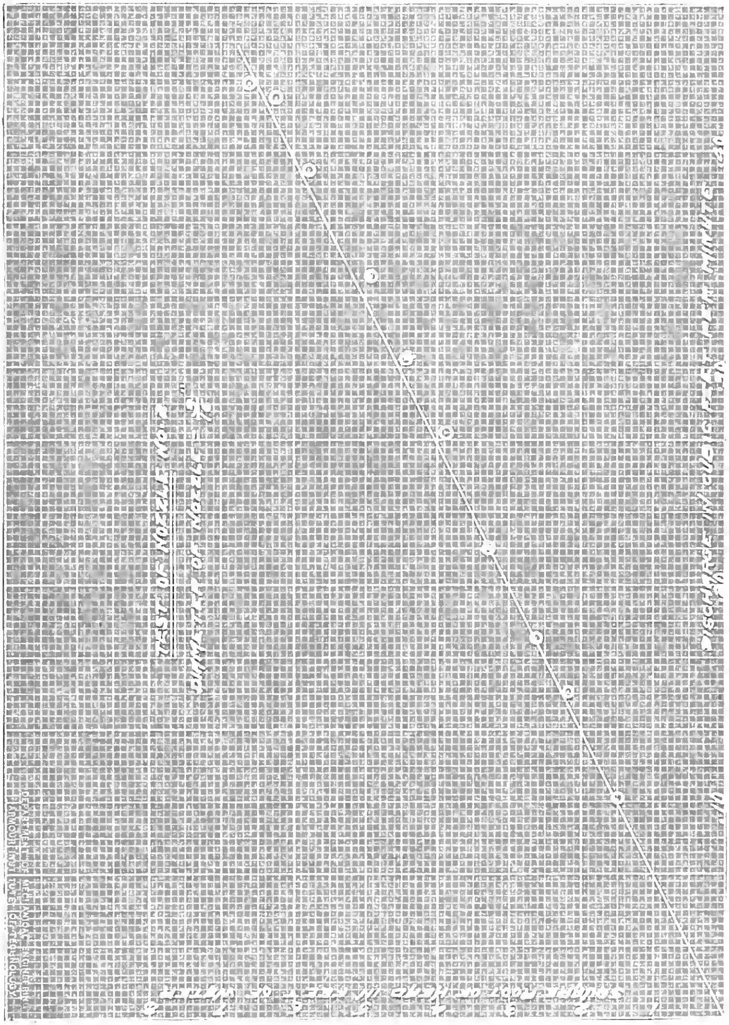
THE STUDY OF AN AIR WASHER

NOZZLE NO.2

Run	Head in Ft. of water	Theor.Disch. C.F.M.	Act.Disch. C.F.M.	Coeff.of Disch.
I	2.26	.I39	.I04I	.750
2	4.52	.I97	.I522	.774
3	6.79	.24I	.I780	.740
4	IO.20	.298	.2I58	.723
5	I4.7I	.344	.26IO	.759
6	I9.25	.406	.3042	.750
7	23.80	.45I	.3400	.754
8	28.30	.492	.352I	.7I8
9	32.80	.529	.3830	.725
IO	38.59	.575	.42IO	.732
II	44.I8	.6I4	.4390	.7I5
I2	49.80	.652	.4740	.726

This nozzle,as shown by the coefficient, produced a course spray,at an angle of 60 degrees with the vertical.The actual discharge as measured at I7 pounds pressure was .4332 c.f.m. or 3.I6 gallons.

Diameter of nozzle equals three sixteenths inches


TEST OF NOZZLE NO. 2
DIAM. OF NOZZLE 3/4"
DISCHARGE IN CU. FT. PER MINUTE
SQUARE ROOT OF HEAD IN FEET OF WATER

THE STUDY OF AN AIR WASHER

TEST OF WASHER

To determine the efficiency of the washer as a dust remover,the method of artificially placing the dust in the air was employed.All windows in the room were closed before starting the test,in order to guard against air currents. The dust was placed in a cheese-cloth bag,and shaken in the room until the room was filled with dust particles.The Hill apparatus was used in this test.

The first attempt made to determine the efficiency was to take a sample of air entering the washer and another leaving the washer.The time interval necessary for taking two separate samples permitted a change in the dust content of entering air sufficient to cause an error.An improvement on this method would be the use of two instruments but error would be introduced unless the strokes of the two pumps could be taken simultaneously.This led to thee

Fig.IO-Connection of Dr.Hill Apparatus to washer

method finally adopted.A Y shaped glass tube was connected to the end of the pump.From this Y two rubber tubes of equal length lead to the washer,one to the entrance,and one directly after the eliminator plates.They were placed on the same level in the washer,so that two samples were received from approximately the same air.By taking a stroke of the pump air was simultaneously drawn through the two tubes.On the end of each tube was placed one of the bulbs ofthe Hill apparatus,containing a cover slip.With the tubes arranged in this manner,runs were taken on different kinds of dust,and the efficiency for each kind was determined.

RUBBER DUST

This dust consisted of very finely powdered pure rubber.All doors and windows were closed,and the room filled with the dust.The temperature of the water was 5I.5 degrees,and the fan ran at 373 r.p.m.The humidity was determined with

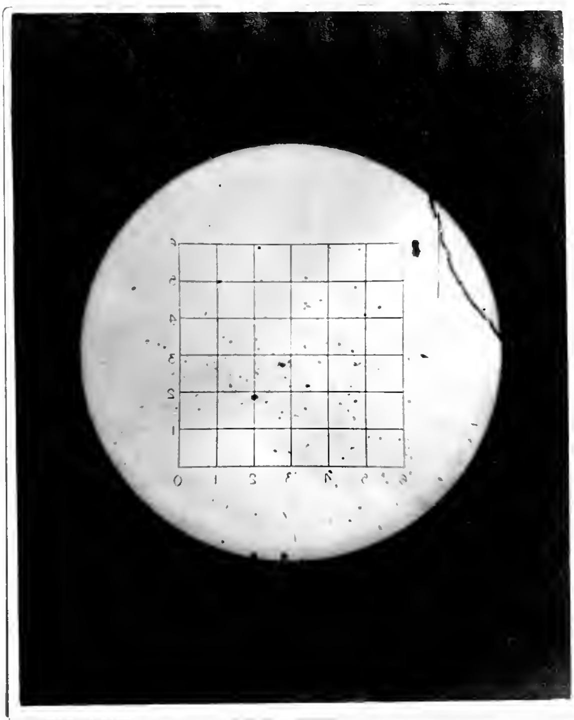


Fig.II-Microphotograph of sample of rubber dust

a sling psychrometer.

Dry Bulb		Wet Bulb		Humidity	
E.	L.	E.	L.	E.	L.
68	59	56.5	56.5	53	9I

Particles in square I	Particles in square 2	Number of strokes	Particles per cu.ft. I	Particles per cu.ft. 2	Efficiency %
		DUST LIGHT			
I56	I6	20	I5000	I530	89.9
I86	I9	20	I7800	I820	90.0
		DUST MEDIUM			
380	34	20	36500	3260	9I.2
368	32	20	35300	3080	9I.0
		DUST HEAVY			
625	47	I0	I20000	9040	92.5
730	57	I0	I40000	I0950	92.3

THE STUDY OF AN AIR WASHER

SAMPLE CALCULATIONS

Determine the efficiency using the figures given.

The number of particles counted on the squared glass of the sample taken before the washer,was I56.Number of strokes taken 20,but since the air passed through two bulbs,the air passing over each cover slip is equivalent to one-half this number of strokes.Hence from the equation:-

D equals 960d divided by n.Now sustituting the values in this formula and

D equals 960xI56x2 divided by 20,which equals I5000 dust particles per cubic foot.

For the sample taken after the air was washed D equals I530 dust particles per cubic foot.The particles removed by the washer is the difference and equals I5000-I530 which equals I3470.

The efficiency thereforequals I3470 divided

by I5000,which equals 89.9 per cent.

THE STUDY OF AN AIR WASHER

STREET DUST

This was obtained from the street,and consisted mostly of sand

Temperature of water 55 degrees

Dry Bulb		Wet Bulb		Humidity	
E.	L.	E.	L.	E.	L.
68	59	56	55	47	73

Particles in square I	Particles in square 2	Number of strokes	Particles per cu.ft. I	Particles per cu.ft. 2	Efficiency %
DUST LIGHT					
504	I5	IO	96900	2880	97.0
540	20	IO	I04000	3840	96.2
DUST MEDIUM					
I370	I8	IO	263000	3460	97.5
828	30	8	I99000	7200	96.4
DUST HEAVY					
864	I7	6	276000	5440	98.I
920	I6	6	294000	5I20	98.2

THE STUDY OF AN AIR WASHER

LAMP BLACK DUST

Temperature of water 55 degrees

Dry Bulb		Wet Bulb		Humidity	
E.	L.	E.	L.	E.	L.
69	66	65	65	8I	94.5

Particles in square		Number of strokes	Particles per cu.ft.		Efficiency %
I	2		I	2	
		DUST LIGHT			
I87	20	IO	36000	3840	89.4
237	24	IO	45500	4600	89.7
		DUST MEDIUM			
I420	I42	8	340000	34I00	90.0
I520	I50	8	365000	36000	90.2
		DUST HEAVY			
2055	I78	6	657000	57I00	9I.2
20I0	I69	6	643000	54I00	9I.6

THE STUDY OF AN AIR WASHER

RATTLER DUST

This dust was obtained from a rattler used for iron castings,and consisted of iron,graphite and some sand.

Temperature of water 58 degrees

Dry Bulb		Wet Bulb		Humidity	
E.	L.	E.	L.	E.	L.
67	60	59	58	63	89

Particles in square I	Particles in square 2	Number of strokes	Particles per cu.ft. I	Particles per cu.ft. 2	Efficiency %
DUST LIGHT					
28I0	2I	20	270000	20I5	99.3
24I0	2I	20	23I000	20I5	99.2
DUST MEDIUM					
3I70	I6	I0	553000	3070	99.4
2900	2I	I0	556000	4030	99.2
DUST HEAVY					
2I60	I5	6	69I000	4800	99.3
3560	2I	8	855000	5050	99.3

THE STUDY OF AN AIR WASHER

WOOD DUST

This dust consisted of very fine particles of wood.

Temperature of water 54 degrees

Dry Bulb E.	Dry Bulb L.	Wet Bulb E.	Wet Bulb L.	Humidity E.	Humidity L.
68	59	57	57	5I	89

Particles in square I	Particles in square 2	Number of strokes	Particles per cu.ft. I	Particles per cu.ft. 2	Efficiency %
DUST LIGHT					
240	8	40	II500	384	96.5
284	9	40	I3600	422	96.7
DUST MEDIUM					
I75	4	IO	33600	770	97.6
206	5	IO	39500	960	97.6
DUST HEAVY					
340	5	8	8I500	I200	98.5
308	6	8	74500	I440	98.I

THE STUDY OF AN AIR WASHER

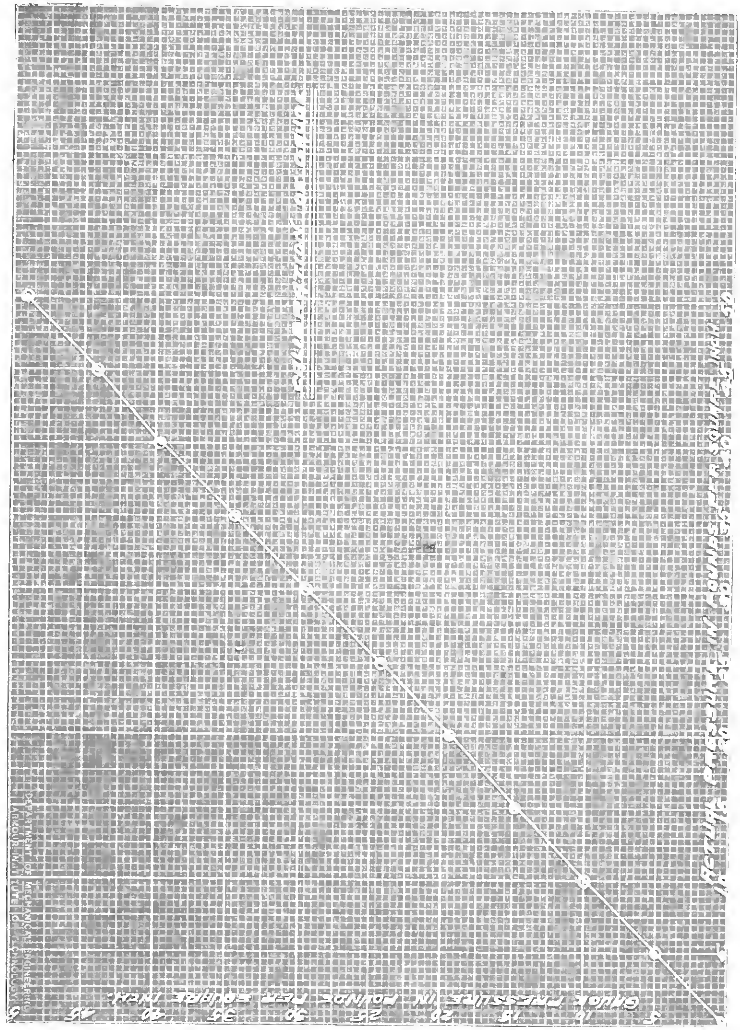
GRAIN DUST

This dust consisted of minute particles of grain and seeds,and was obtained from a grain elevator.

Temperature of water 55 degrees

Dry Bulb		Wet Bulb		Humidity	
E.	L.	E.	L.	E.	L.
67	58	57	56	54	89

Particles in square I	Particles in square 2	Number of strokes	Particles per cu.ft. I	Particles per cu.ft. 2	Efficiency %
DUST LIGHT					
364	5	40	I7500	240	98.6
400	6	40	I9200	288	98.5
DUST MEDIUM					
,802	7	20	77000	673	99.0
776	8	20	74500	768	99.0
DUST HEAVY					
522	4	IO	I00000		99.2
677	5	IO	I30000		99.2


ACTUAL PRESSURES IN POUNDS PER SQUARE INCH
GAUGE PRESSURES IN POUNDS PER SQUARE INCH
DEPARTMENT OF MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY

THE STUDY OF AN AIR WASHER

CONCLUSIONS FROM DATA OBTAINED

The different kinds of dust caused a range in efficiency from 89.4 to 99.4 per cent.

The efficiency increases with the number of particles in the air.

FUTURE CONSIDERATIONS

(I) The investigation of the effects of the temperature of the water on the efficiency would lead to interesting results.

(2) The effects of varying the number of nozzles would also prove very interesting.